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Analysis of Earthquake Data from the Greater Los Angeles Basin and Adjacent Offshore Area, Southern California

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ABSTRACT

We synthesize and interpret local earthquake data recorded by the Caltech/USGS Southern California Seismographic Network (SCSN/CISN) in southern California. The goal is to use the existing regional seismic network data to: (1) refine the regional tectonic framework; (2) investigate the nature and configuration of active surficial and concealed faults; (3) determine spatial and temporal characteristics of regional seismicity; (4) determine the 3D seismic properties of the crust; and (5) delineate potential seismic source zones. Because of the large volume of data and tectonic and geologic complexity of the area, this project is a multi-year effort and has been divided into several tasks.

RESULTS

Data-driven Accelerogram Synthesis with Deep Generative Models

We developed a method for synthesizing earthquake accelerograms with artificial intelligence (AI) algorithms (Florez et al., 2020). Our method is a data-driven approach that uses an unsupervised deep learning algorithm to learn probability distributions for large accelerogram datasets. We used a type of model called Generative Adversarial Networks (GANs) (Goodfellow et al., 2014), which was developed in the field of computer vision to simulate realistic photographs given a large set of real photos (Karras et al., 2018). An example of this impressive advance is in Figure 1, where each image displays a person that is not real.

GANs are composed of two deep neural networks that are designed to perform distinct tasks. One network is designed to generate realistic images on demand, given a random vector of white noise, while the second network is designed to discriminate between real images and AI generated images. These two networks are trained in an iterative adversarial context, learning from a real dataset, until convergence. The remarkable realism of the AI-generated photographs in Figure 1 motivates the potential application of this technology to seismic data.

Figure 1. *These are AI-generated photographs of fake people. Figure from (Karras et al., 2018).*

Our approach to synthesizing ground motions uses a special variant of a GAN called a conditional GAN (Mirza & Osindero, 2014), where the generated data samples are drawn from a conditional probability distribution. The conditions are specified by the user. We created a conditional GAN that takes as input magnitude, source-receiver distance, and Vs,30 (Florez et al., 2020). The model would therefore be able to generate accelerograms consistent with these 3 prescribed characteristics. We assembled a dataset of nearly 300,000 accelerograms from moderate-to-large earthquakes recorded in Japan over the last 20 years. After training, we can synthesize examples of accelerograms limitlessly. Some examples are shown in Figure 2.

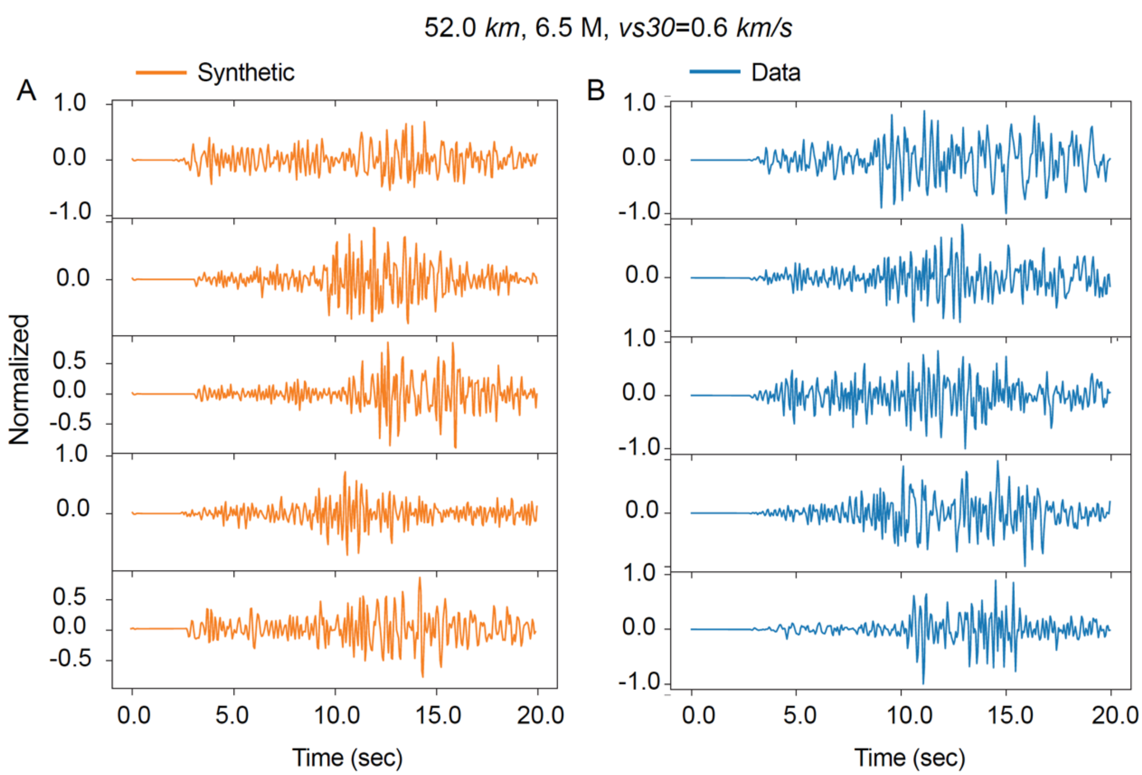

Figure 2. *Examples of AI-generated accelerograms alongside real accelerograms with the same design characteristics.*

Our method is able to synthesize very realistic accelerograms that have the same characteristics as exhibited by the real data, including S-P time, frequency content, and amplitudes. To see this, Figure 3 compares statistics of simulated and data accelerograms in both the Fourier and time domain. It is clear that the synthetic accelerograms exhibit the expected characteristics of the real data with the same statistical variability.

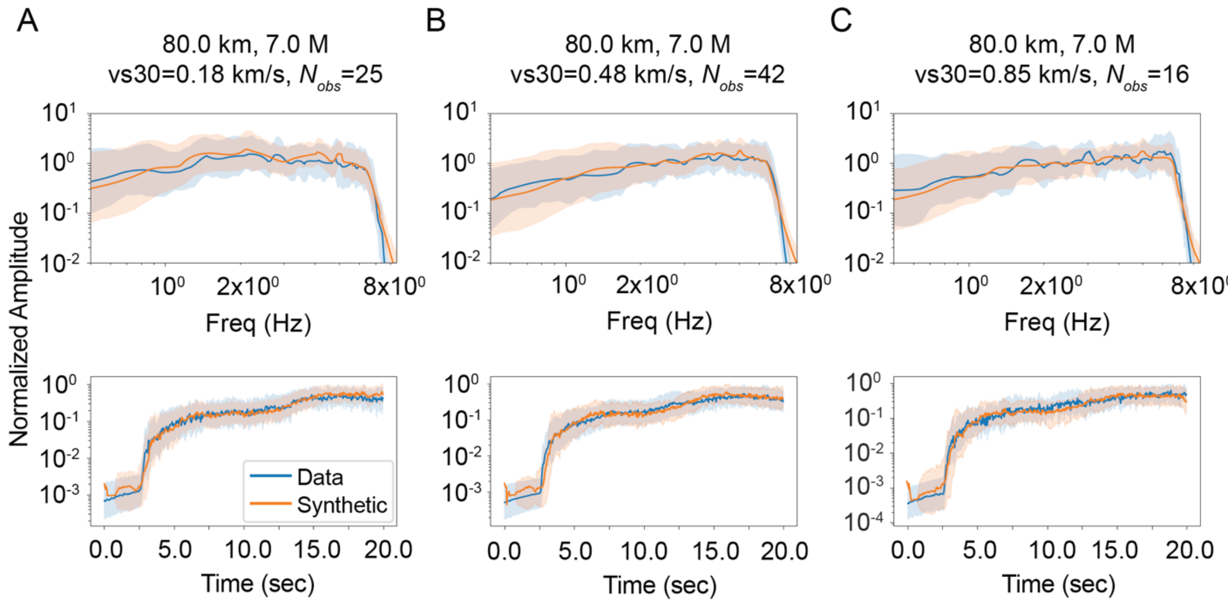

Figure 3. *Statistical comparison of accelerograms.*

The Normal Faulting 2020 Mw5.8 Lone Pine, Eastern California Earthquake Sequence

The 2020 M_w 5.8 Lone Pine earthquake, the largest earthquake on the Owens Valley fault zone, eastern California, since the 19th century, ruptured an extensional step over in that fault. Owens Valley separates two normal faulting regimes, the western margin of the Great Basin and the eastern margin of the Sierra Nevada, forming a complex seismotectonic zone, and a possible nascent plate boundary (Figure 4). Foreshocks began on 22 June 2020; the largest M_w 4.7 foreshock occurred at ~6 km depth, with primarily normal faulting, followed ~40 hours later on 24 June 2020 by a M_w 5.8 mainshock at ~7 km depth. The sequence caused overlapping ruptures across a ~0.25 km^2 area, extended to ~4 km^2, and culminated in a ~25 km^2 aftershock area. The mainshock was predominantly normal faulting, with a strike of 330° (north-northwest), dipping 60° to 65° to the east-northeast. Comparison of background seismicity and 2020 Ridgecrest aftershock rates showed that this earthquake was not an aftershock of the Ridgecrest mainshock. The M_w-m_B relationship and distribution of ground motions suggest typical rupture speeds. The aftershocks form a NNW-trending, NNE dipping, 5 km long distribution, consistent with the rupture length estimated from analysis of regional waveform data. No surface rupture was reported along the 1872 scarps from the 2020 M_w 5.8 mainshock although the dipping rupture zone of the M_w 5.8 mainshock projects to the surface in the general area. The mainshock seismic energy triggered rock falls at high elevations (>3.0 km) in the Sierra Nevada at distances of 8 to 20 km, and liquefaction along the western edge of Owens Lake. Because there were ~30% fewer aftershocks than for an average southern California sequence, the aftershock forecast probabilities were lower than expected. ShakeAlert, the earthquake early warning system, provided first warning within 9.9 s, as well as subsequent updates. Also, see Hauksson et al. 2020, (published in Seismological Research Letters).

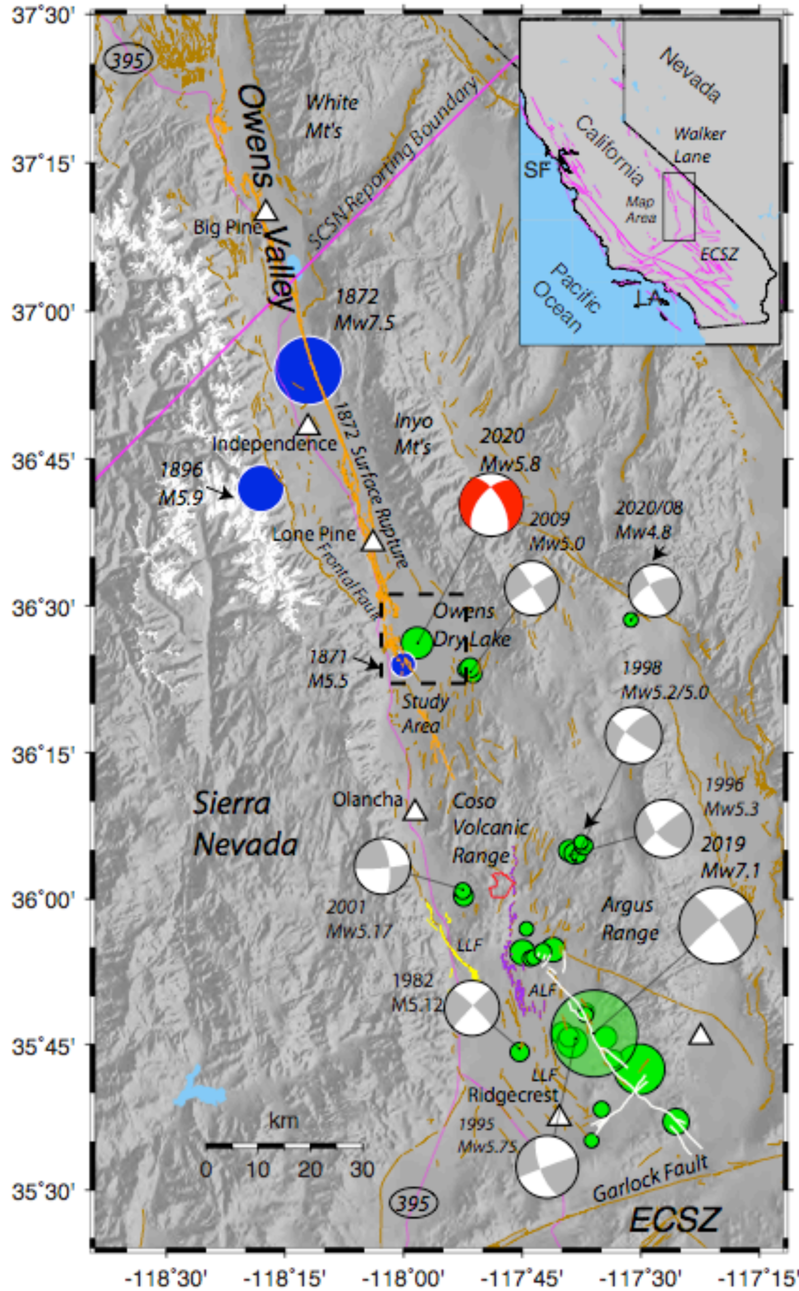

Figure 4. Map of Owens Valley and adjacent regions in eastern California. Major earthquakes that occurred in the late 19th century are shown as labelled blue dots scaled with magnitude (Felzer and Cao, 2008; Ellsworth, 1990). Location of this map is shown in upper-right corner. Late Quaternary faults from Jennings and Bryant (2010) are shown in brown. The 1872 Mw 7.5 surface rupture is shown in orange (Haddon *et al.*, 2016). Seismicity of M≥5 since 1980 is shown as green dots scaled with magnitude, with lower hemisphere focal mechanisms shown for significant events. The focal mechanism of the 2020 Mw 5.8 Lone Pine earthquake is shown in red. The 2020 August Mw 4.8 Stovepipe Wells earthquake is also included for reference. The detailed study area that is shown in later figures is outlined with dashed black lines. The SCSN northern reporting boundary is shown in magenta. ECSZ - eastern California shear zone. The US (395) highway is shown as a curvy magenta line and local towns are marked as triangles.

Project Data

The first project is a machine learning modeling study (Florez et al. 2020). The manuscript describing the details of the study is freely available here:

http://arxiv.org/abs/2011.09038.

In the second project (Hauksson et al., 2020), we analyzed waveforms and parametric data from the Caltech/USGS Southern California Seismic Network (SCSN); doi: 10.7914/SN/CI; stored at the Southern California Earthquake Data Center. doi:10.7909/C3WD3xH1. Caltech began operating a seismic network in the late 1920s and seismic stations in the Ridgecrest area in 1947. The hypocenters and magnitudes from 1930 to 1980 are from the Caltech/USGS southern California earthquake catalog (Hutton *et al.,* 2010). The seismicity parameters from 1981 to the end of 2019 are from the waveform-relocated catalog as described by Hauksson *et al*. (2012) and Hauksson *et al*., (2020). However, we use GrowClust for relocating the most recent version of this catalog (Trugman and Shearer, 2017). The catalogs used in this study can be accessed here:

https://scedc.caltech.edu/data/alt-2011-dd-hauksson-yang-shearer.html
https://scedc.caltech.edu/data/alt-2011-yang-hauksson-shearer.html

The Lone Pine and adjacent regional seismicity was detected by the SCSN automated picker and reviewed by data analysts. USGS aftershock forecasts use data obtained from the SCSN via ComCat at https://earthquake.usgs.gov/earthquakes/search/ (last accessed Sept. 4, 2020) and the current forecast and parameters can be found at:
https://earthquake.usgs.gov/earthquakes/eventpage/ci38457511/oaf (last accessed September 4, 2020).

The ShakeAlert Twitter message for the mainshock:
https://twitter.com/USGS_ShakeAlert/status/1275850444506529792

Additional information about aftershock forecasting :
https://earthquake.usgs.gov/data/oaf/

Additional information about the Did-You-Feel-It-Data (DYFI) data,
https://earthquake.usgs.gov/earthquakes/eventpage/ci39493944/dyfi/intensity (data downloaded 17 July 2020; last accessed 12 Oct. 2020).
No new software was developed as part of this research.

Refereed publications supported by this grant

Florez, M. A., Caporale, M., Buabthong, P., Ross, Z. E., Asimaki, D., & Meier, M.-A. (2020). Data-driven Accelerogram Synthesis using Deep Generative Models. *ArXiv:2011.09038 [Physics, Stat]*. Retrieved from http://arxiv.org/abs/2011.09038

Hauksson, E., B. Olson, A. Grant, J. R. Andrews, A. I. Chung, S. E. Hough, H. Kanamori, S. K. McBride, A. J. Michael, M. Page, Z. E. Ross, D. E. Smith, and S. Valkaniotis (2020). The Normal Faulting 2020 Mw5.8 Lone Pine, Eastern California Earthquake Sequence, *Seismol. Res. Lett*. in press, Dec. 2020.

Abstracts for grant related oral, reports, or poster presentations

Hauksson, E., B. Olson, J. R. Andrews, A. I. Chung, H. Kanamori, Z. E. Ross, and S. Valkaniotis (2020). The Normal Faulting 2020 Mw5.8 Lone Pine, Eastern California Earthquake Sequence, *(Abstract_ AGU Fall Meeting)*, Dec. 2020

Hauksson, E. and L. M. Jones (2020). Seismotectonics, seismicity, and stress state of the Ridgecrest Coso region from the 1930s through 2019; (Abstract) submitted to GSA, Cordilleran Section - 116th Annual Meeting; Pasadena CA., May 2020. Meeting Cancelled.

Nicholson, C., C. C. Sorlien, T. E. Hopps, M. J. Kamerling, and E. Hauksson (2020), Anomalous Uplift at Pitas Point and the 2019 Ventura River Earthquake Swarm: Whose Fault is it Anyway?; Abstract submitted to: Pacific Section-AAPG Oxnard CA, meeting, April 2020 – Meeting Cancelled.

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Hutton, L. K., J. Woessner, and E. Hauksson (2010). Seventy-Seven Years (1932 - 2009) of Earthquake Monitoring in Southern California. *Bull. Seismol. Soc. Am*, *100*(2), 423–446. https://doi.org/10.1785/0120090130

Trugman, D. T., and P. M. Shearer (2017). GrowClust: A Hierarchical Clustering Algorithm for Relative Earthquake Relocation, with Application to the Spanish Springs and Sheldon, Nevada, Earthquake Sequences, *Seismol. Res. Lett.*, 88 (2A), 379–391, doi:10.1785/0220160188 .